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DOWNSTREAM EFFECTS OF THE LEVEE OVERTOPPING AT WILKES-BARRE, PA. DURING TROPICAL STORM AGNES

by

ARLEN D. FELDMAN

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A rainfall-runoff model for Tropical Storm Agnes in the Susquehanna River Basin was developed. A reservoir operation model was also developed in order to compute regulated streamflows. Susquehanna River flood discharges were computed for Wilkes-Barre, PA, for both levee nonovertopping and levee overtopping conditions. The levee overtopping conditions were modeled using storage-outflow relations developed from water surface profiles for the Wilkes-Barre reach. If the levee had been (continued)

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20. ABSTRACT (Continued)

sufficiently high to contain the flow, the peak discharge would have been increased and occurred earlier. Translating this earlier and larger peak downstream would have resulted in practically a 10 percent increase in the peak discharge at Sunbury. This large peak is due to both the increased peak at Wilkes-Barre and coincident timing with the peak coming from the West Branch of the Susquehanna River. Since the actual peak flow at Sunbury was within inches of the top-of-levee, a potentially disasterous flood could have occurred at Sunbury if the Wilkes-Barre levee had not been overtopped.

DOWNSTREAM EFFECTS OF THE LEVEE OVERTOPPING AT WILKES-BARRE, PA, DURING TROPICAL STORM AGNES[1]

By

Arlen D. Feldman[2]

ABSTRACT

A rainfall-runoff model for Tropical Storm Agnes in the Susquehanna River Basin was developed. A reservoir operation model was also developed in order to compute regulated streamflows. Susquehanna River flood discharges were computed for Wilkes-Barre, PA, for both levee nonovertopping and levee overtopping conditions. The levee overtopping conditions were modeled using storage-outflow relations developed from water surface profiles for the Wilkes-Barre reach. If the levee had been sufficiently high to contain the flow, the peak discharge would have been increased and occurred earlier. Translating this earlier and larger peak downstream would have resulted in practically a 10 percent increase in the peak discharge at Sunbury. This large peak is due to both the increased peak at Wilkes-Barre and coincident timing with the peak coming from the West Branch of the Susquehanna River. Since the actual peak flow at Sunbury was within inches of the top-of-levee, a potentially disasterous flood could have occurred at Sunbury if the Wilkes-Barre levee had not been overtopped.

BACKGROUND FOR THE STUDY

The Hydrologic Engineering Center was requested by the Corps of Engineers, North Atlantic Division, to participate in a special hydrologic study of Tropical Storm Agnes, June 1972, in the Susquehanna and three other east coast river basins. The flood waters produced by Agnes rainfall along with local frontal storms produced record flooding in many parts of the Susquehanna River Basin. The town of Wilkes-Barre, PA, was particularly hard-hit when flood waters overtopped the levees and inundated the flood plain on which most of the city was built. Cities downstream from Wilkes-Barre were also flooded, but the severity of the

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(1) For presentation at the 54th Annual Meeting of American Geophysical Union, April 1973, Washington, D.C.

(2) Research Hydraulic Engineer, The Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, California.

downstream flooding was reduced considerably by the disasterous flood storage in the city of Wilkes-Barre.

The Agnes study included flood frequency, rainfall-runoff, reservoir system operation, and water surface profile analyses in the Susquehanna, Schuylkill, Potomac and James River Basins. The Corps of Engineers contracted with Anderson Nichols, Inc., a Boston-based consulting engineering firm, to perform the water surface profile analyses in the Susquehanna River Basin. The water surface profile studies were used to verify existing Muskingum flood routing criteria or to replace it with storage-outflow relationships where the linear Muskingum method was not adequate.

STUDY OBJECTIVES AND MODELS USED

There were two major objectives in the Agnes study: investigate the effect of this large event on previously computed flood frequency relationships; and develop mathematical models of rainfall-runoff and reservoir operation. Results of the Susquehanna and Schuylkill River studies have been reported in "Hydrologic Study - Tropical Storm Agnes, Report No. 2" (reference 1). The mathematical models are to be used to assist in studying new flood control projects and to compute regulated and natural frequency curves. Two generalized computer programs developed by The Hydrologic Engineering Center were used: HEC-1, Flood Hydrograph Package (reference 2), and HEC-5, Reservoir System Operation for Flood Control (reference 3). A third computer program of The Hydrologic Engineering Center, HEC-2, Water Surface Profiles (reference 4), was used by the consulting engineering firm for their part of the project.

RAINFALL-RUNOFF

Basin data for the HEC-1 rainfall-runoff and HEC-5 reservoir operation models were obtained from the National Weather Service, U.S. Geological Survey, and the Baltimore District of the Corps of Engineers. The National

Weather Service provided an isohyetal map of rainfall during the Agnes flood and hourly rainfall data at recording stations. The Baltimore District had previously conducted a comprehensive study of the Susquehanna River Basin above Harrisburg, PA, the results of which were published in Appendix D, "Hydrology," Susquehanna River Basin Study Report (reference 5). The hydrology appendix delineated over 140 hydrologic subbasins and their unit hydrograph characteristics. A map of the Susquehanna River Basin is shown in figure 1. The report also specified the Muskingum routing criteria for all of the reaches connecting the subbasins and forming the river system. Reservoir storage characteristics, general operation criteria and actual Agnes operating results were obtained from the Baltimore District. The U.S. Geological Survey provided stream gage data where available and made estimates of flows where gages were washed out.

The rainfall input to the rainfall-runoff model, HEC-1,was constructed using the isohyetal rainfall pattern to determine average total rainfall for each subbasin and the recorder data to distribute this total rainfall period by period. Emphasis was placed on reproducing the observed volume of runoff while maintaining the timing and magnitude of the peak within reasonable limits. Samples of computed and observed hydrographs at major river stations are shown in figure 2. Table 1 summarizes pertinent data about Agnes rainfall and runoff.

In order to be able to reconstitute the rainfall-runoff process for Agnes, it was not necessary to use the reservoir system operation model, HEC-5, because the observed reservoir releases could be given to the HEC-1 model. The observed reservoir outflows were inputed directly into HEC-1 and runoff was computed only for the areas below the reservoirs. The principal use of the reservoir operation model was for evaluation of future changes in reservoirs, levees and channel improvements on regulated frequency curves.

COMPUTATION OF FLOOD FLOWS IN THE WILKES-BARRE REACH

The rainfall-runoff model was used to compute the inflow to the

Wilkes-Barre Reach of the Susquehanna River during Tropical Storm Agnes. The aforementioned rainfall, loss rate, unit graph and linear routing criteria were used to compute this flow. Although the linear Muskingum routing criteria was not theoretically applicable in some of the routing reaches during the high flows of Agnes, the inflow to the Wilkes-Barre Reach and the flows in most other parts of the basin appear to be good estimates of the observed flows when using the linear routing. The closest upstream verification was at The Towanda, PA, gage and the comparison of computed and observed discharges were shown in figure 2b.

Flood routing through the Wilkes-Barre Reach was accomplished by two different methods. First, the flows were routed by the linear Muskingum criteria assuming that the levees were sufficiently high to contain the Agnes flood flow. Second, the flows were routed by a nonlinear storage-outflow method (modified Puls) considering the existing topography and levee heights in the reach before the flood.

The results of the two routings are shown in figure 3. The peak discharge of the linear routing is seen to be 27,000 cfs larger than the nonlinear routing and 17,000 cfs larger than the observed peak discharge. The peak discharge for the nonlinear routing is 10,000 cfs less than the observed peak discharge.

It was difficult to simulate the levee overtopping condition at Wilkes-Barre because of the manner in which the event occurred. The flood waters were not believed to have eroded the levee on the rising limb of the hydrograph. Inspection of the levee area after the flood indicated that the levee did not erode upon overtopping, but erosion occurred as flood waters returned to the river channel on the falling limb of the hydrograph. Because of the difference in storage volumes before and after the levee eroded, it was necessary to develop two storage-outflow relationships for the Wilkes-Barre reach--one for the rising and another for the falling limb of the flood hydrograph.

The two storage-outflow curves for the Wilkes-Barre reach were computed with HEC-2, Water Surface Profiles. In the first case levees were considered

intact. In the second case levees were considered to be completely destroyed.

The transition between the two storage-outflow curves was instantaneous when river stages reached the top of the levee. For computational purposes it was necessary to make two passes through the computer to route through the entire hydrograph. The results of the first pass ($S + \frac{Q}{2}$ routing) were utilized to the point just beyond the peak discharge. That furnished the starting storage with which to begin the recession computation using the second storage-outflow curve. There was some loss in volume because of basement and other storage in the city, but this was not a significant portion of the 225,000 acre feet of flood waters in the city at the time of the maximum flow of the river.

DOWNSTREAM EFFECTS OF THE LEVEE OVERTOPPING

The downstream effects of the levee overtopping at Wilkes-Barre were analyzed by routing the hydrographs which resulted from the two routings (with and without infinite levees in the Wilkes-Barre Reach) on downstream to Harrisburg. Both routings took into account the flows from intervening areas in computing the total Agnes flow at Harrisburg. The routed and intervening flows between Wilkes-Barre and Harrisburg were computed in the same manner for both of the hydrographs from the Wilkes-Barre Reach. Muskingum routing coefficients were used for all the reaches below Wilkes-Barre on the Susquehanna River and on its tributaries.

The results of the two computed flows and the observed flows are shown in table 2. Figure 2c showed the comparison of computed and observed flows at Harrisburg for the levee nonfailure routing at Wilkes-Barre. The levee overtopping routing of the flows to Harrisburg was essentailly the same shape with a reduced peak as noted in table 2.

It is noted that the computed peak flows (for the levee overtopping case which occurred) differ from the observed peak flows by as much as

10 percent. Differences between computed and observed flows at most gage locations on the mainstem and tributaries of the Susquehanna River system, were less than 10 percent. The Agnes event was of such a magnitude (estimated to be a 300 to 400-year return period at Harrisburg) that many of the discharge gages did not function properly or were destroyed. For many of the gages that did function correctly, the observed stages were at or beyond the upper limit of the historical rating curve. During the time (August-October 1972) when this project was being undertaken, it was not uncommon to have the estimates of river discharges be updated as the flood was studied in more detail.

Every possible effort was made within the time constraints of this project to reproduce the observed flows. Because of the differences between the computed and observed flows and because of the uncertainty in the observed flows themselves, a more valid analysis of the effects of the levee overtopping can be accomplished by a comparison of the two computed flows. The differences between computed flows were shown in table 2. The largest increase in flow would have occurred at Sunbury if the levee had not been overtopped. This increase would have been about 71,000 cfs.

The potentially large increase in flow at Sunbury was due to both the larger peak at Wilkes-Barre (about 27,000 cfs) and the coincident timing with the peak flow coming from the West Branch of the Susquehanna River. The peak flow at Wilkes-Barre, without the levee overtopping, occurred about 20 hours earlier than the peak flow with the levee being overtopped. The difference between the two hydrographs was 77,000 cfs at the time of the earlier peak flow at Wilkes-Barre. The occurrence of the peak at this earlier time would have made it coincide with the peak flow from the West Branch when they met at Sunbury. The difference of 77,000 cfs would reduce to about 71,000 cfs when routed to Sunbury.

The potential increase in flow was not as large at Danville because Danville is above the confluence with the West Branch and the coincident timing could only have been with the local flow. The increase in flow

was also less at Harrisburg; this was due to the effects of the routing from Sunbury to Harrisburg as well as the effect of the large amount of tributary flow which would have occurred in either case.

The Agnes flood peak that occurred at Sunbury was within inches of the top of the levee at that location. The increase in flow that would have occurred if the Wilkes-Barre levee had not been overtopped would have undoubtedly brought about severe flooding at Sunbury and increased the flooding at Harrisburg. It is difficult to determine whether the inundation of Sunbury and the increased flooding at Harrisburg would have caused more or less economic loss than what actually occurred at Wilkes-Barre. Damage estimates for floods of this magnitude are subject to much uncertainty as are the flows themselves.

SUMMARY

The Agnes flood in the Susquehanna River Basin above Harrisburg, PA, was modeled for existing conditions and for the possible conditions of a higher levee at Wilkes-Barre. The potential impact of a ficticious, high levee which could contain the flow at Wilkes-Barre was analyzed in terms of changes in downstream discharges. It was found through a comparison of two sets of computed flows that the Agnes flood could have been about 71,000 cfs larger at Sunbury and 58,000 cfs larger at Harrisburg if the Wilkes-Barre levee had not been overtopped. The increased flow would have been due to both a larger and earlier peak discharge at Wilkes-Barre that would have coincided with the peak discharge from the West Branch at Sunbury.

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1. U. S. Army Corps of Engineers, "Hydrologic Study - Tropical Storm Agnes - Report No. 2," North Atlantic Division, October 1972.
2. U. S. Army Corps of Engineers, "HEC-1, Flood Hydrograph Package," The Hydrologic Engineering Center, Davis, CA, January 1973.

3. U. S. Army Corps of Engineers, "HEC-5, Reservoir System Operation for Flood Control," The Hydrologic Engineering Center, Davis, CA, October 1972.

4. U. S. Army Corps of Engineers, "HEC-2, Water Surface Profiles," The Hydrologic Engineering Center, Davis, CA, December 1971.

5. Susquehanna River Basin Study Coordinateing Committee, Susquehanna River Basin Study Report, Appendix D, "Hydrology," June 1970.

FIGURES

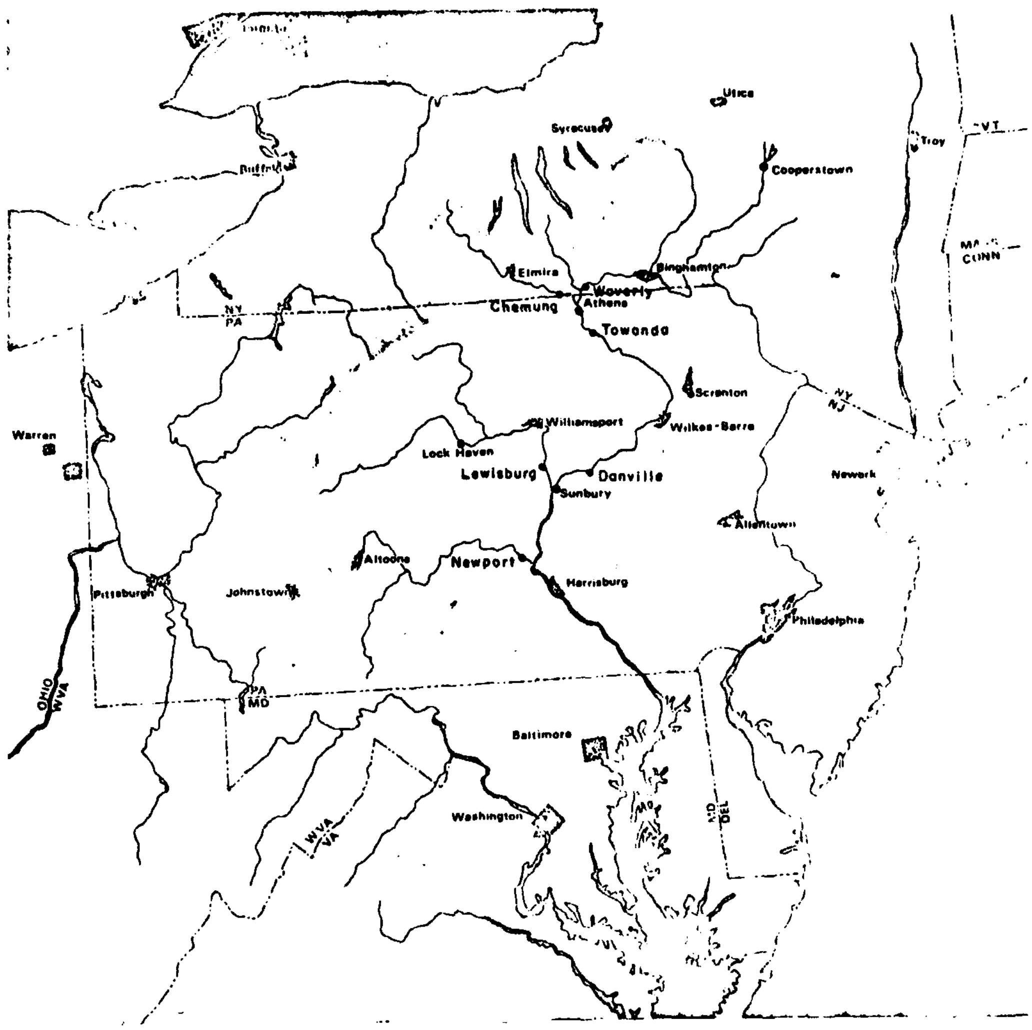

Figure 1. Map of Susquehanna River Basin

LEGEND: 0 Computed Value
* Observed Value

NOTE: When observed and computed values are equal, only the observed value symbol is printed.

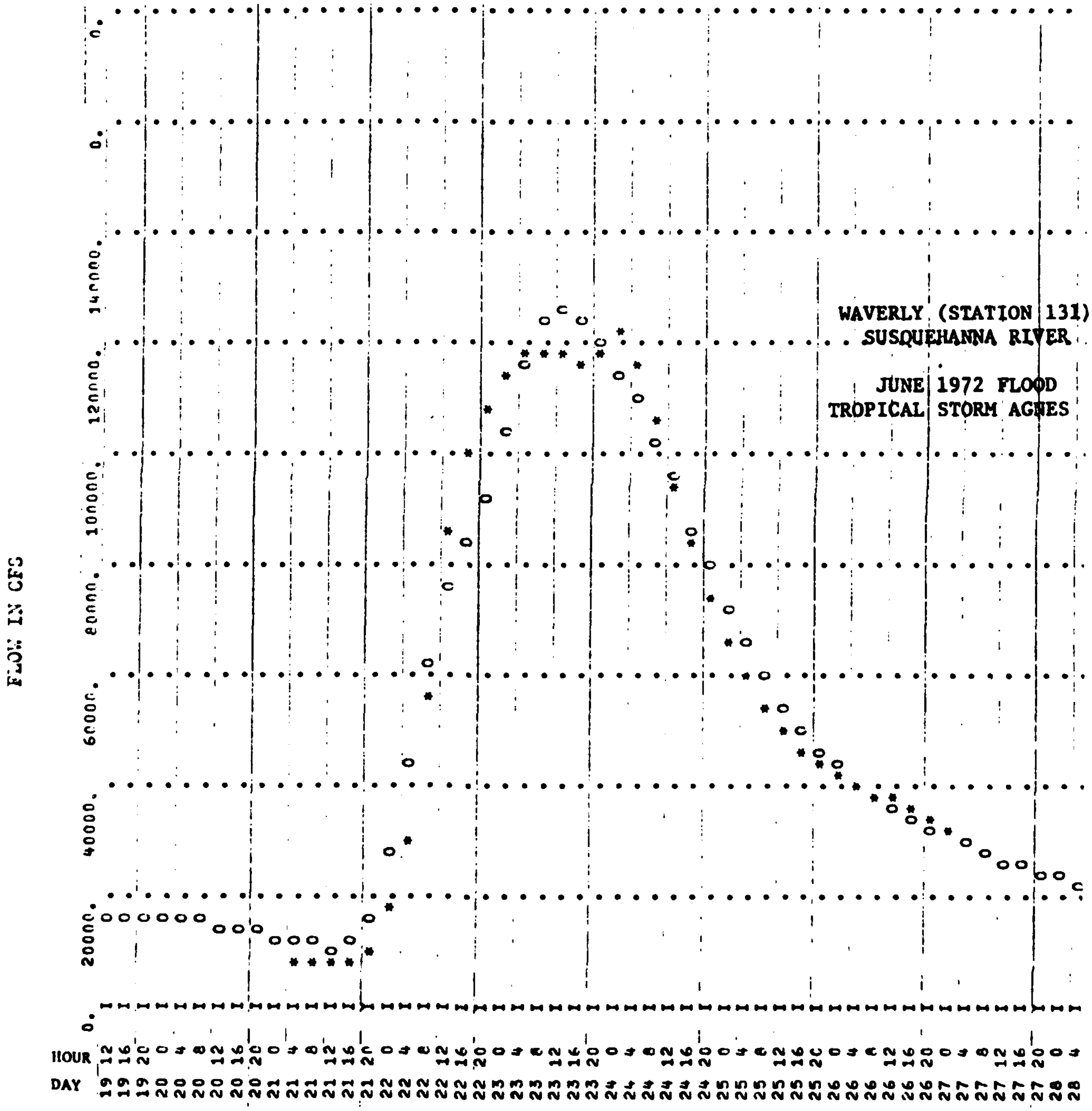

Figure 2a. Comparison of Observed and Computed Flows

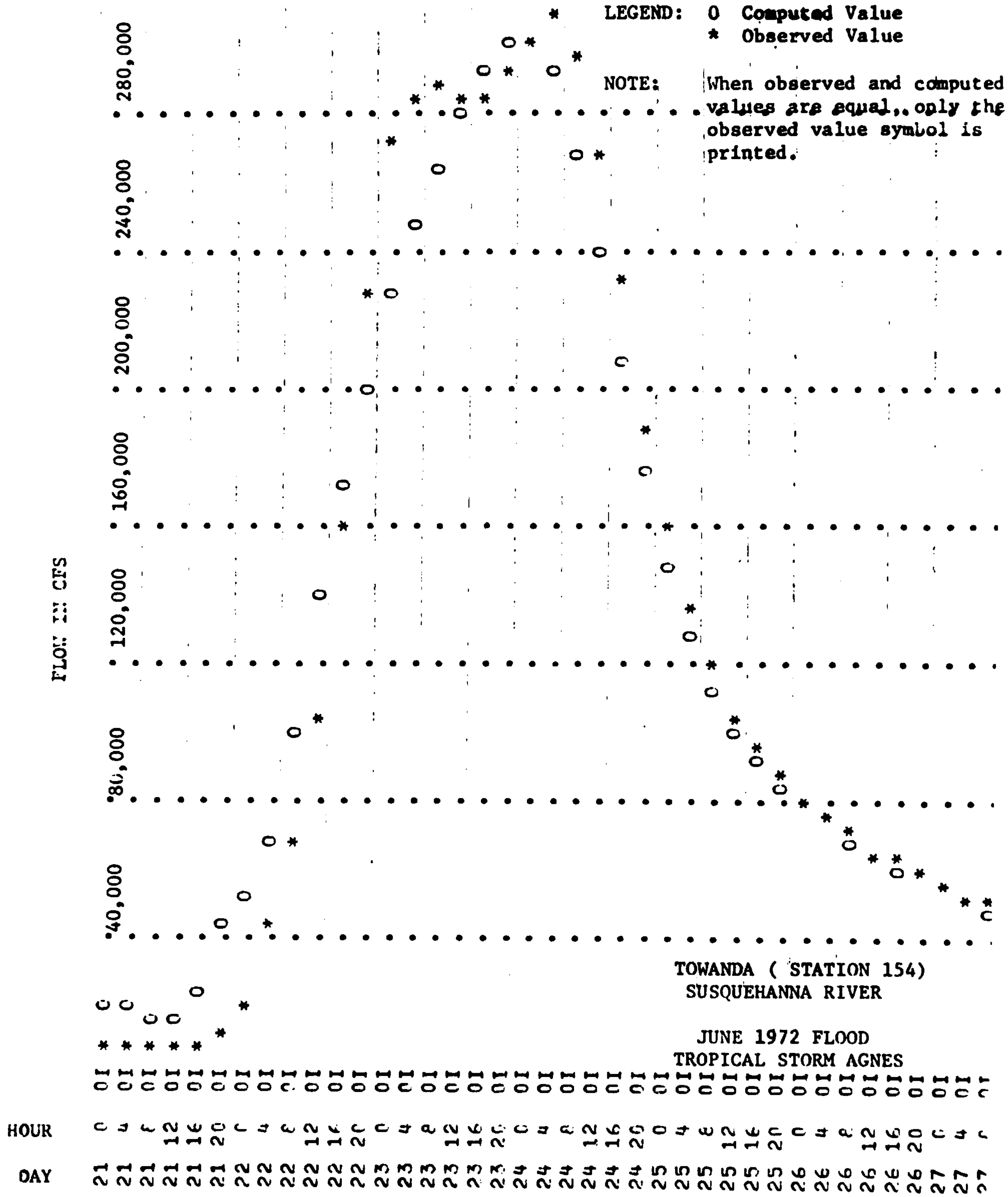

Figure 2b. Comparison of Observed and Computed Flows

LEGEND: 0 Computed Value
* Observed Value

NOTE: When observed and computed values are equal, only the observed value symbol is printed.

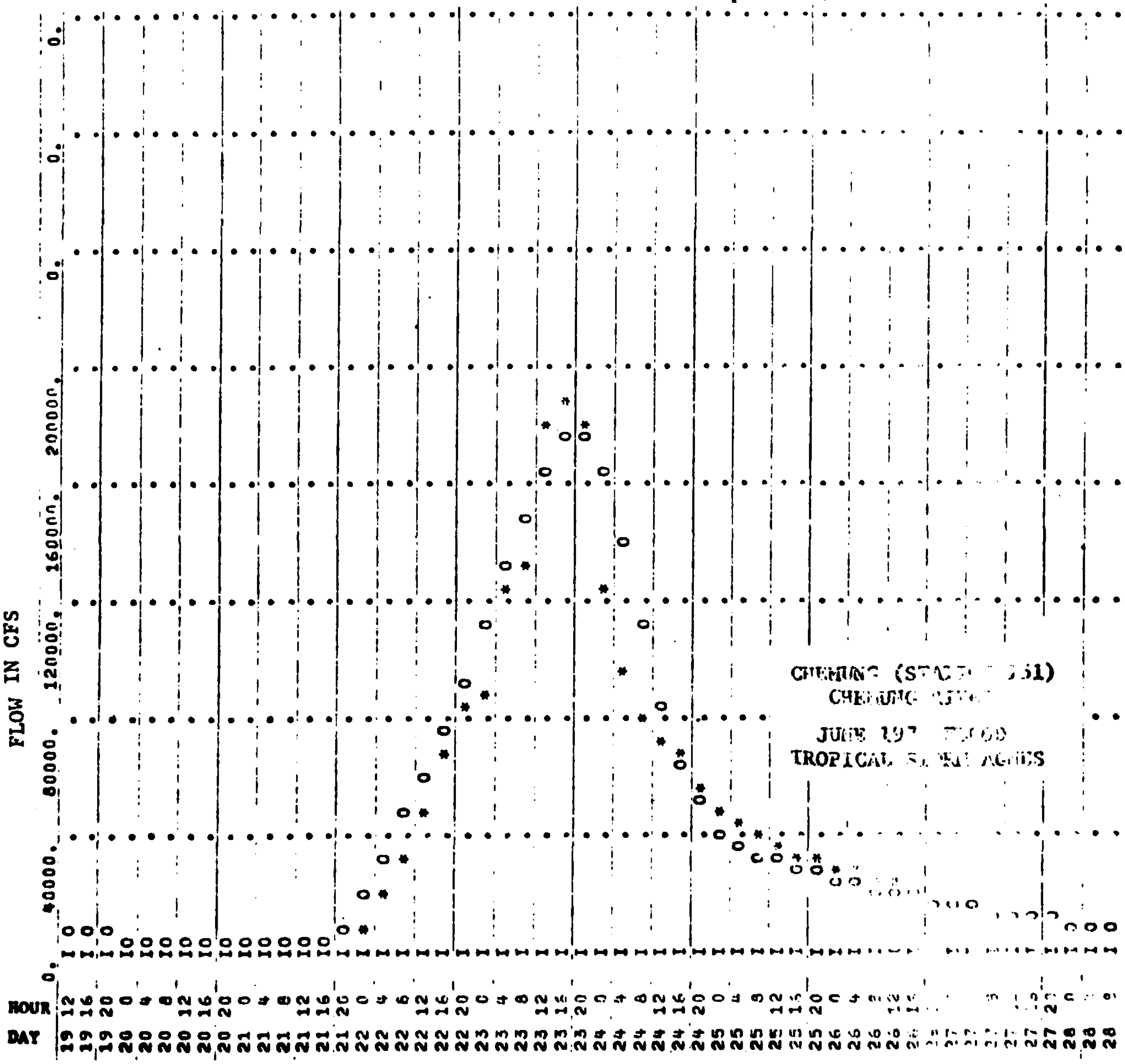

Figure 2c. Comparison of Observed and Computed Flows

LEGEND: 0 Computed Value
* Observed Value

NOTE: When observed and computed values are equal, only the observed value symbol is printed.

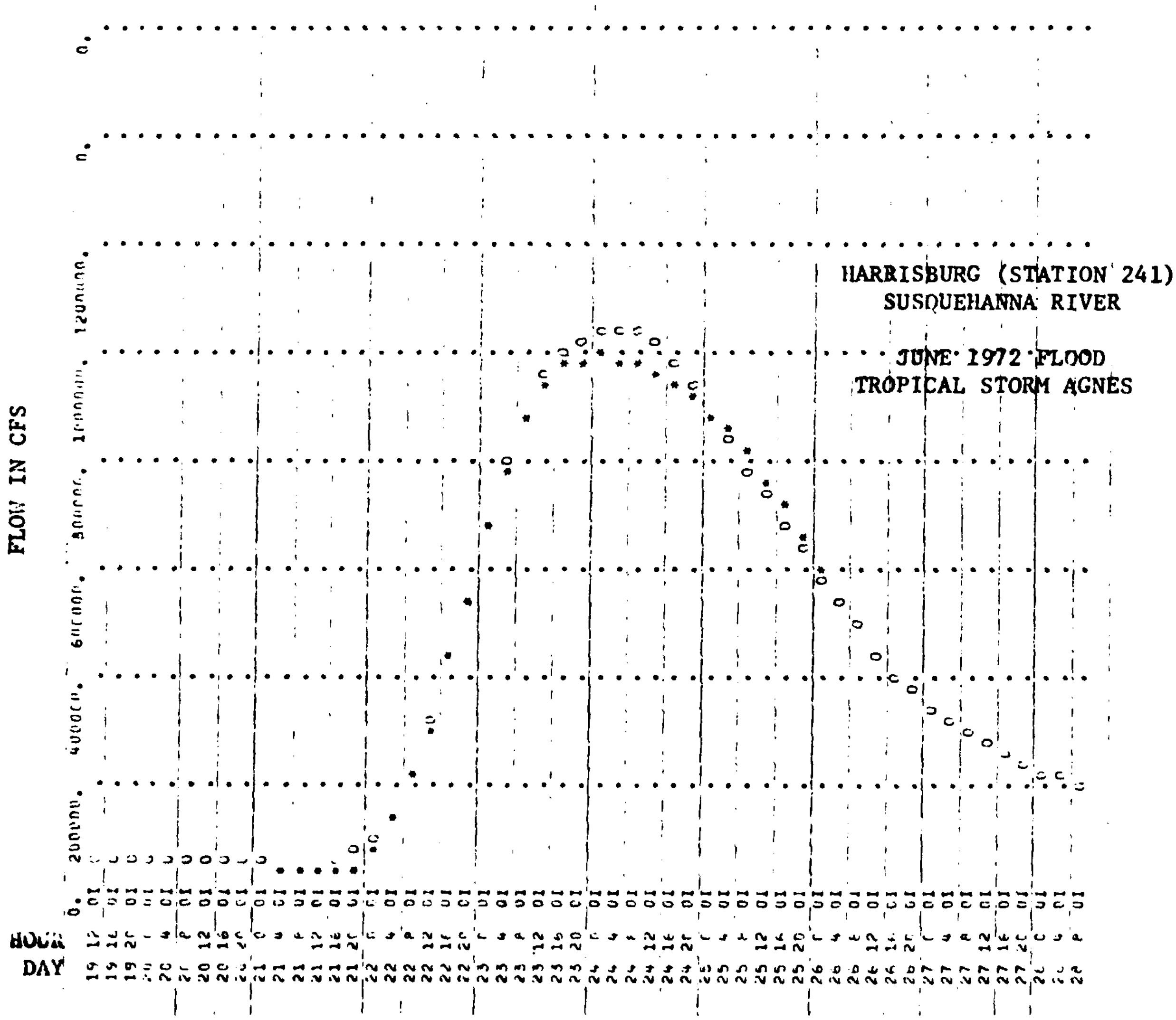

Figure 2d. Comparison of Observed and Computed Flows

LEGEND: 0 Computed Value
* Observed Value

NOTE: When observed and computed values are equal, only the observed value symbol is printed.

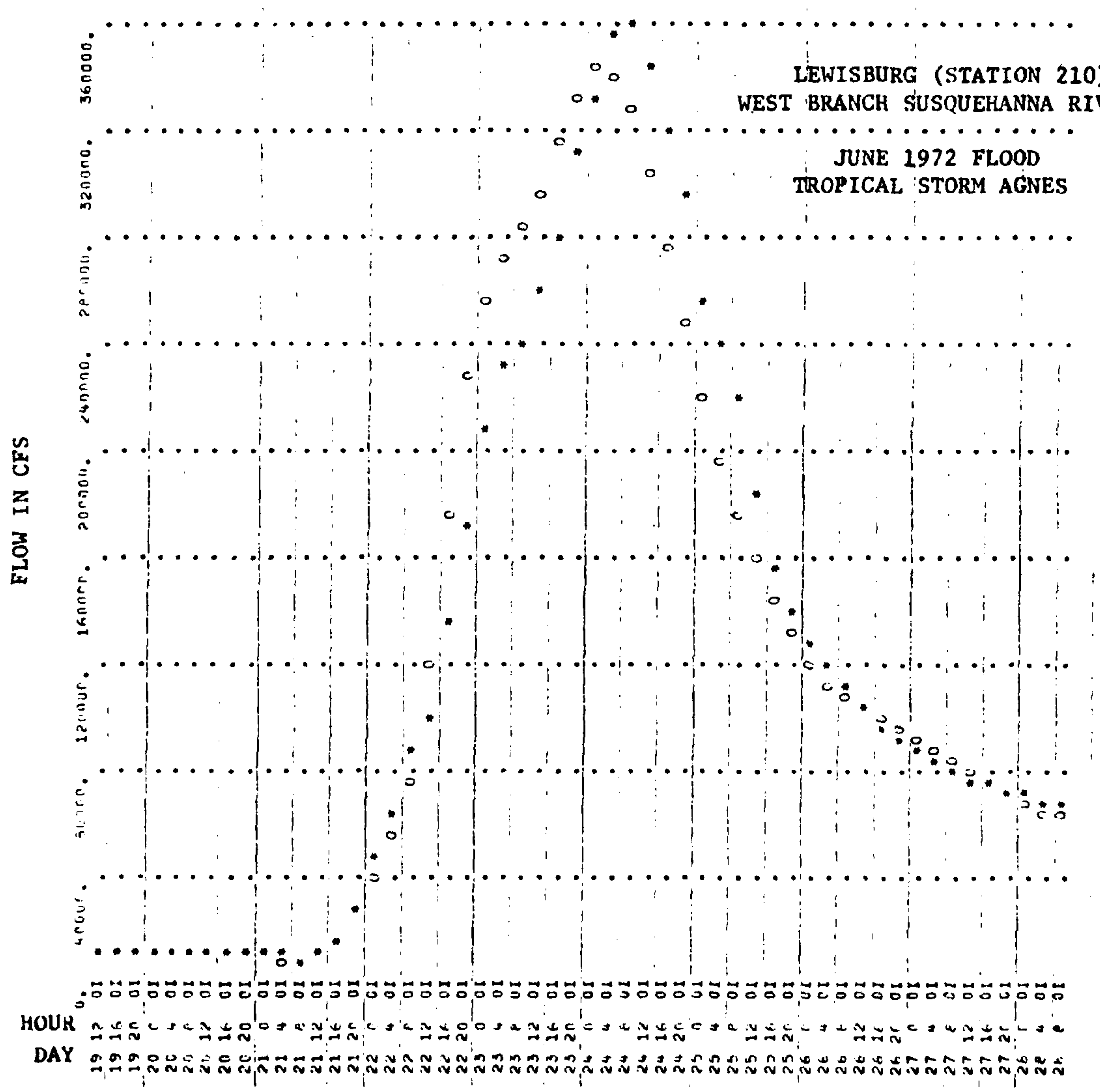

Figure 2e. Comparison of Observed and Computed Flows

LEGEND: 0 Computed Value
* Observed Value

NOTE: When observed and computed values are equal, only the observed value symbol is printed.

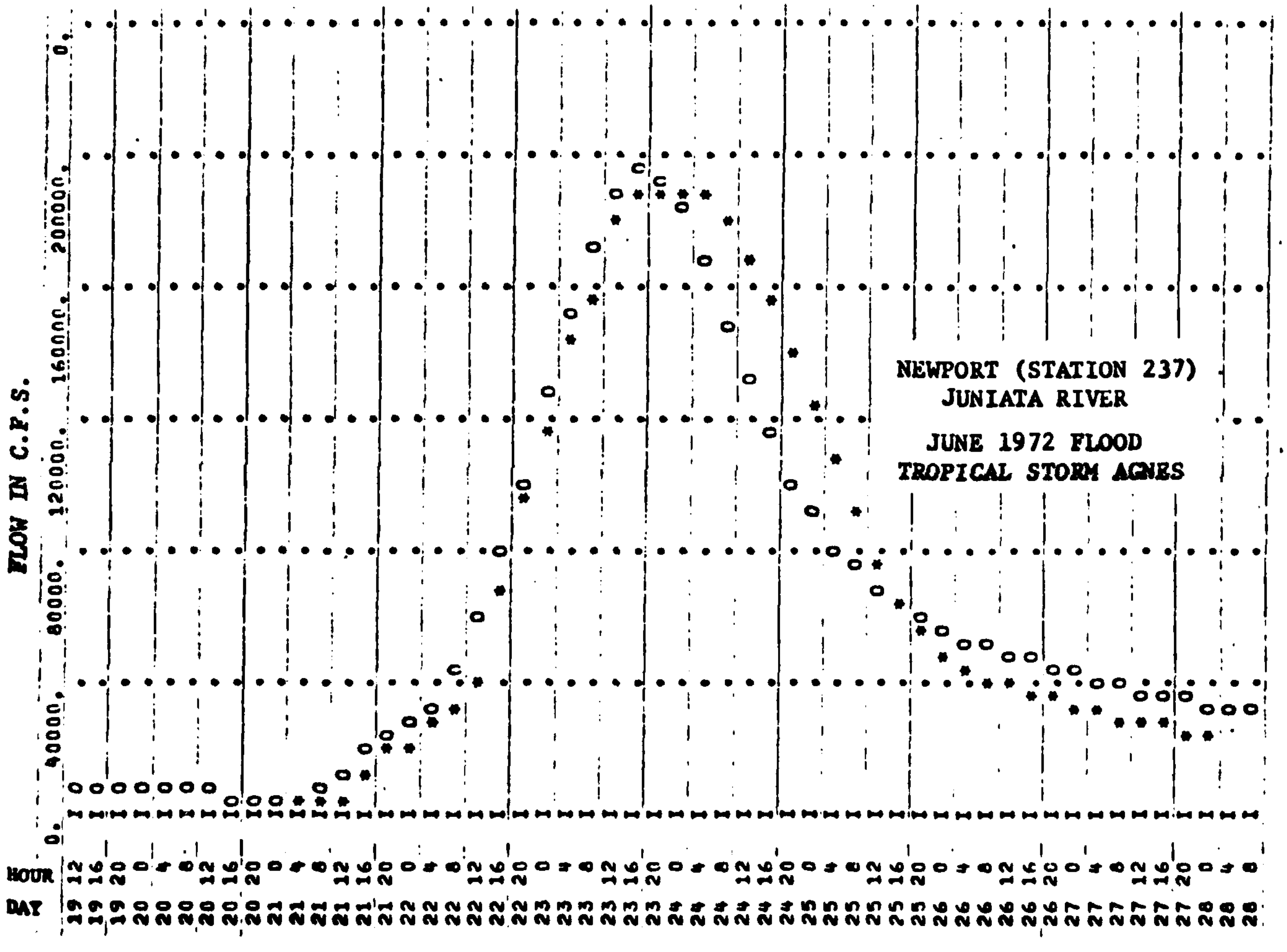

Figure 2f. Comparison of Observed and Computed Flows

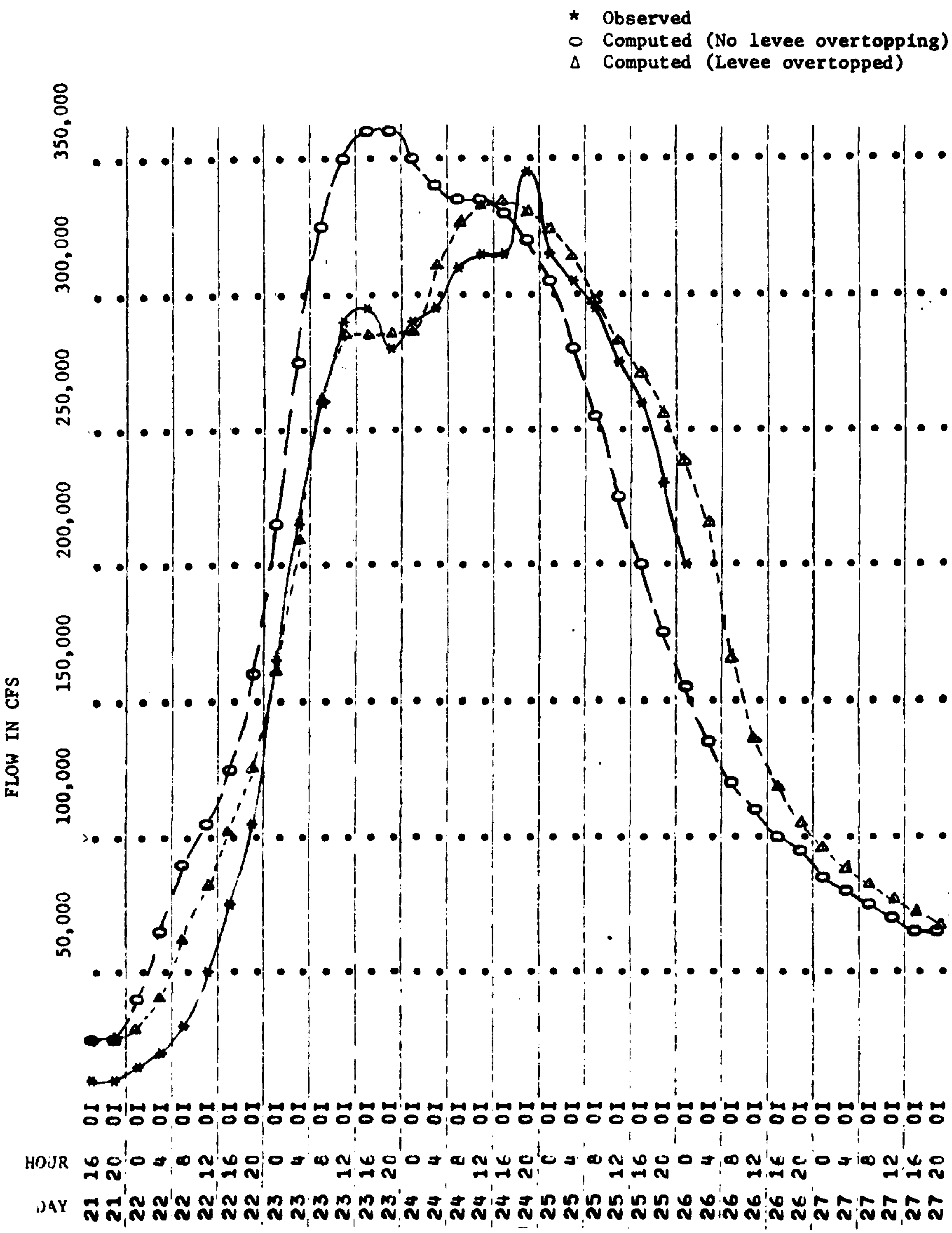

Figure 3. Comparison of Flows at Wilkes-Barre

TABLES

Table 1. Summary of Agnes Rainfall and Runoff

Location	Drainage Area (mi^2)	Rainfall (in) Agnes	Rainfall (in) PMS(1)	Runoff Volume(2) Acre-feet	Runoff Volume(2) Inches	Runoff Factor(3) (% of Rainfall)
Susquehanna River above:						
Waverly, NY	4,780	4.47	15.5	869,000	3.4	76
Wilkes-Barre, PA	9,960	6.63	14.2	2,490,000	4.7	71
Harrisburg, PA	24,102	9.08	12.7	7,813,000	6.1	67
Chemung River above:						
Chemung, NY	2,530	9.38	18.4	768,000	5.7	61
West Branch Susquehanna River above:						
Lewisburg, PA	6,847	9.92	16.4	2,367,000	6.5	66
Juniata River above:						
Newport, PA	3,356	10.17	18.8	1,143,000	6.4	58

(1) Probable Maximum Storm, U. S. Weather Bureau, "Hydrometeorological Report No. 40," May 1965.

(2) Volume of flow for period June 21-28, 1972, inclusive.

(3) For Tropical Storm Agnes.

Table 2. Flows in 1000 cfs

Station	Observed	Levee Holding	Levee Overtopped	Difference Between Computed Flows
Wilkes-Barre	346	363	336	27
Danville	372	408	360	48
Sunbury	620	758	687	71
Harrisburg	1,000	1,023	965	58

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